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Finite Element Magnetic Analysis of the Cornell Seven-Pole Wiggler Prototype

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Abstract— *A 2-dimensional finite element magnetic analysis of a longitudinal cross-section of a seven-pole wiggler prototype (designed by A. Mikhailichenko at Cornell and to be built by the Laboratory of Nuclear Studies at Cornell) has been performed. One of the main purposes of this analysis was to obtain the Lorentz force distribution in the coils; which would be transferred to a separate mechanical model to perform the mechanical stress analysis of the wiggler prototype during cool-down and excitation.*

Summary

Figure 1 shows a schematic of the Cornell's seven-pole wiggler prototype [1]. We have performed a magnetic analysis of this seven-pole wiggler prototype to extract the Lorentz forces acting on the coils, which we require for performing a mechanical analysis. A similar analysis for a three-pole wiggler model is presented in reference [2]. We have used the magnetic properties of 1010 steel in our analysis as reported in reference [2]. The area representation of the finite element model used is shown in Figure 2. We discretized the model using 4-noded PLANE13 elements. Each half of the coil is divided into 6 x 4 finite elements. The current excitation in the coils is provided below:

1. CENTRAL COILS:

   Total Number of turns = 510
   Current = 510 x 186.275 A = 95 kA
   Coil Dimension = 1.0 " x 0.75"
   Current Density = 1.963 x 10^8 A/m^2

2. END COILS:

- Main Coil
  Total Number of turns = 310
  Current = 310 x 186.275 A = 57.745 kA
  Coil Dimension = 0.608" x 0.75"
  Current Density = 1.963 x 10^8 A/m^2 (196.3 A/mm^2)
- Trim Coil
  Total Number of turns = 650
  Current = 650 x 5 A = 3.25 kA
  Coil Dimension = 0.392" x 0.75"
  Current Density = 0.1713 x 10^8 A/m^2 (17.13 A/mm^2)

The wiggler central field is plotted in Figure 3. Figures 4 to 9 present the results of the magnetic solution. Figures 10 to 22 present the results of the Lorentz forces acting on the coils. Mesh convergence has been checked by using 11 x 8 elements for each coil-half. The Lorentz forces changed by less than 1%, implying that the chosen mesh size is sufficient. Note that the wiggler central field has a weak dependence on the iron properties. However, the magnetic field in the coil and thereby the Lorentz forces are strongly dependent on the chosen iron properties. Table 1 presents a summary of the Lorentz forces acting on the central coil. The coil dimensions were used to convert the Lorentz forces into the pressure values.

Table 1: Summary of the Lorentz pressure for the coils of the seven-pole wiggler model.

	X-direction Lorentz Pressure (MPa)	***Y-direction Lorentz Pressure (MPa)***
Center Coil	**5.06**	**3.34**

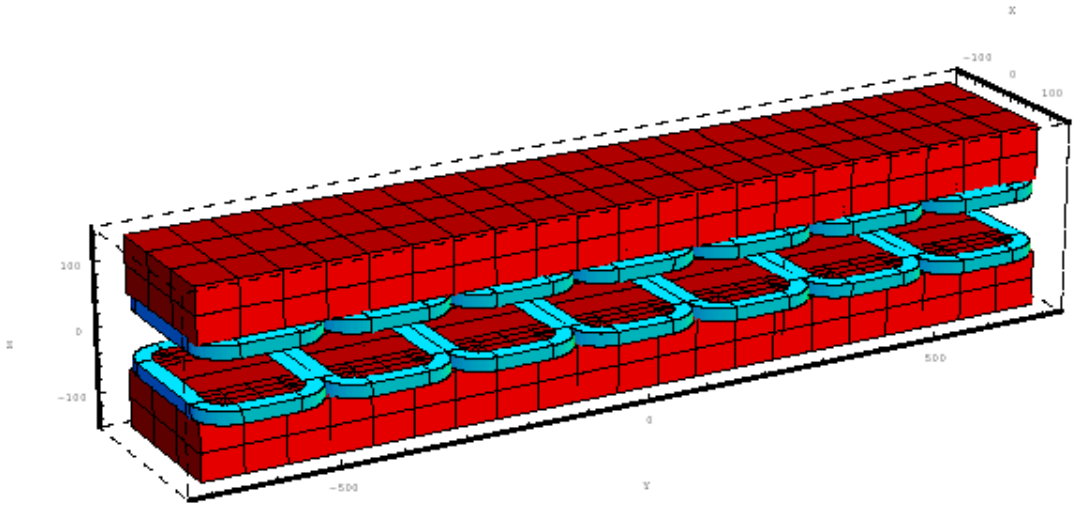

Figure 1: Seven-pole wiggler coil and iron arrangement. Coil is in blue and iron in red. Dimensions are in mm. (Source: Gerry Dugan's report [1]).

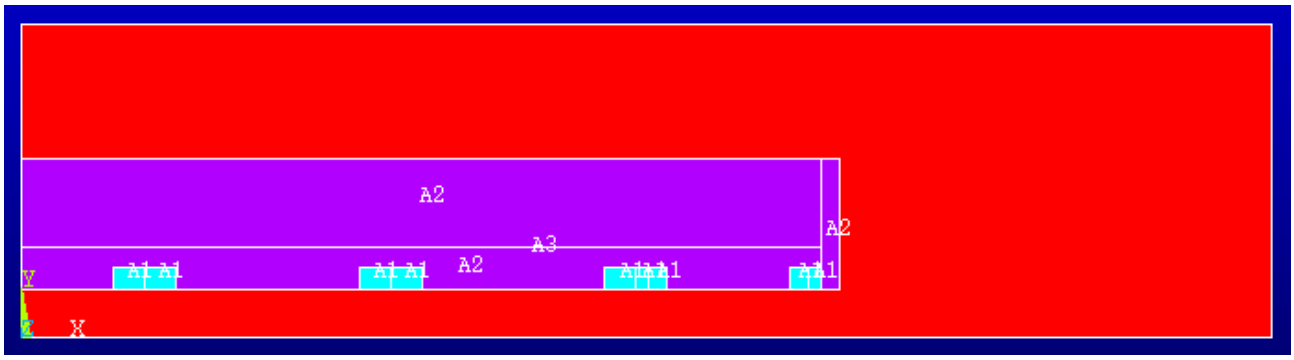

Figure 2: Area representation of the seven-pole wiggler prototype. Due to the symmetry around the YZ plane, only half of the model is considered. The light blue color represents the coils, purple is the iron, and red is air.

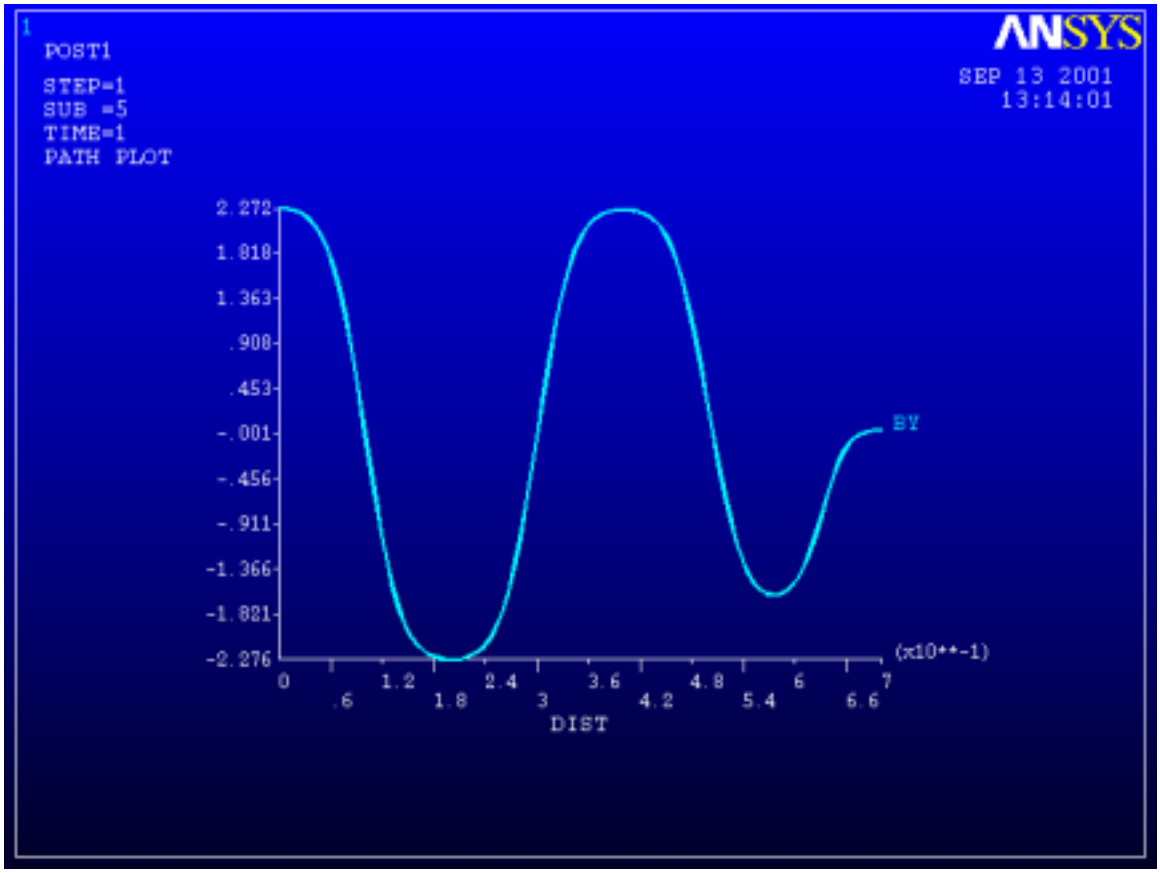

Figure 3: Y-component of the magnetic field (By) along the length of the wiggler model. The field is along the X-axis and for Y=0.

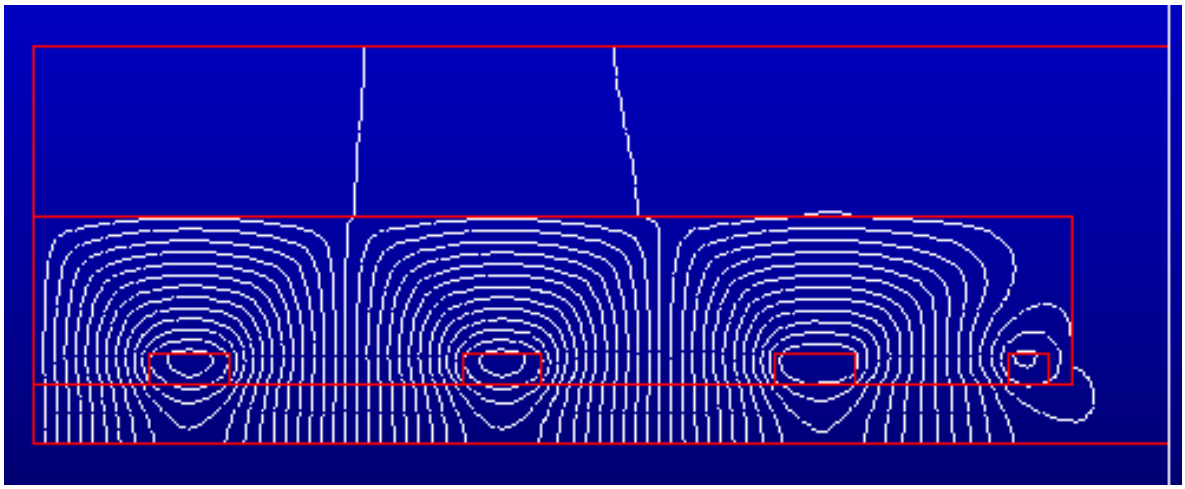

Figure 4: Magnetic flux lines for the seven-pole wiggler model.

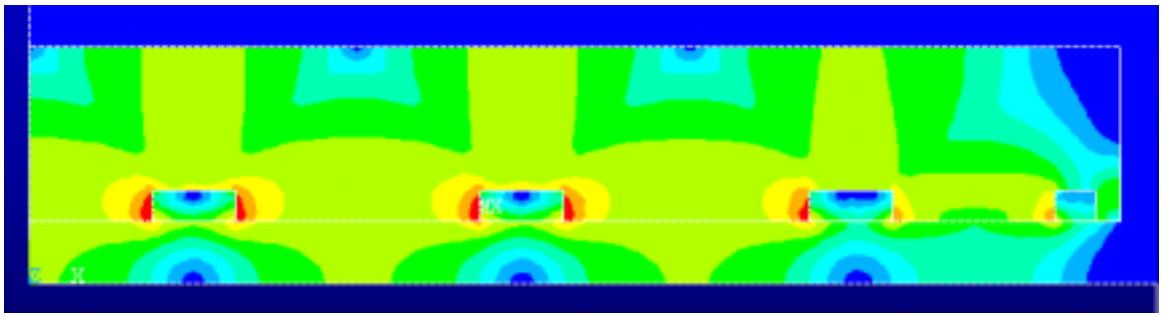

Figure 5: Contour plot of the total magnitude of the magnetic field (in Tesla) for the seven-pole wiggler model. Please refer to Fig. 6 for contour levels.

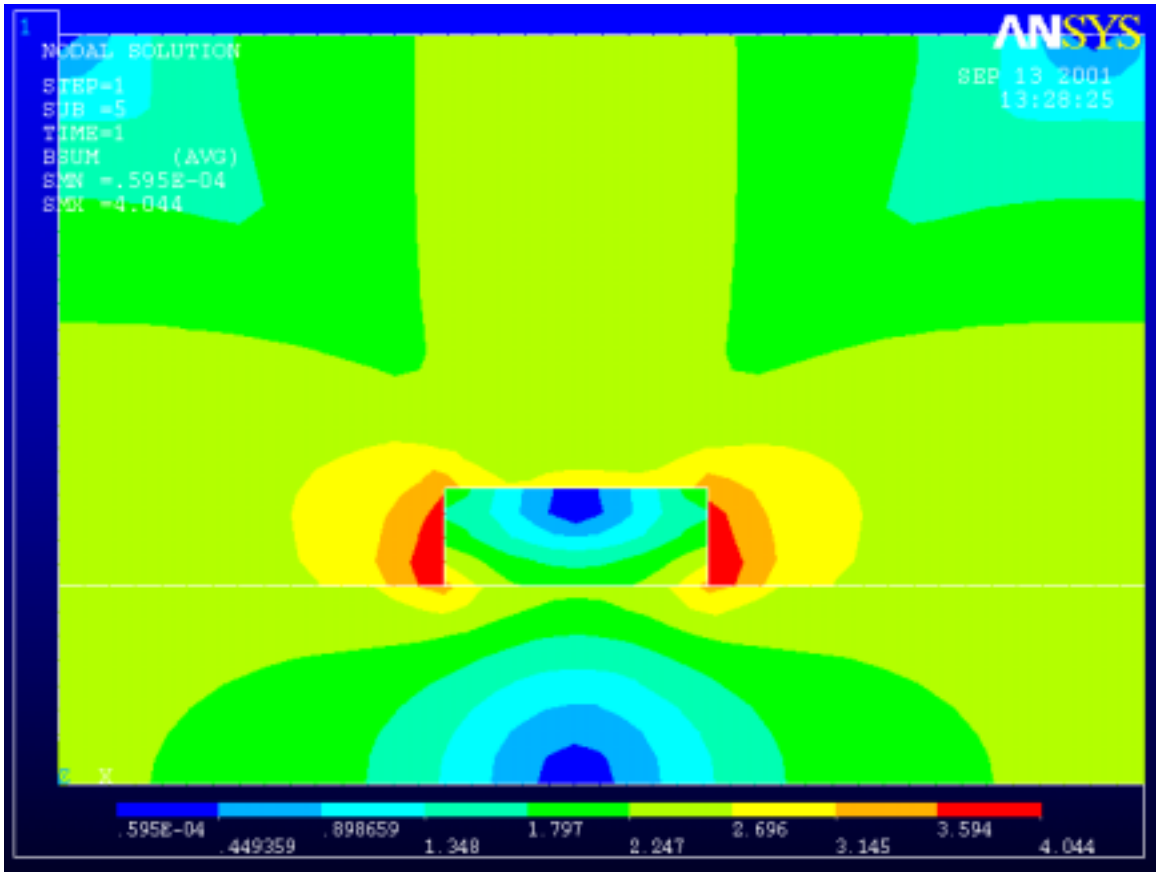

Figure 6: Contour plot of the total magnitude of the magnetic field (in Tesla) for the seven-pole wiggler model. The left most coil group in Fig. 5 is shown here.

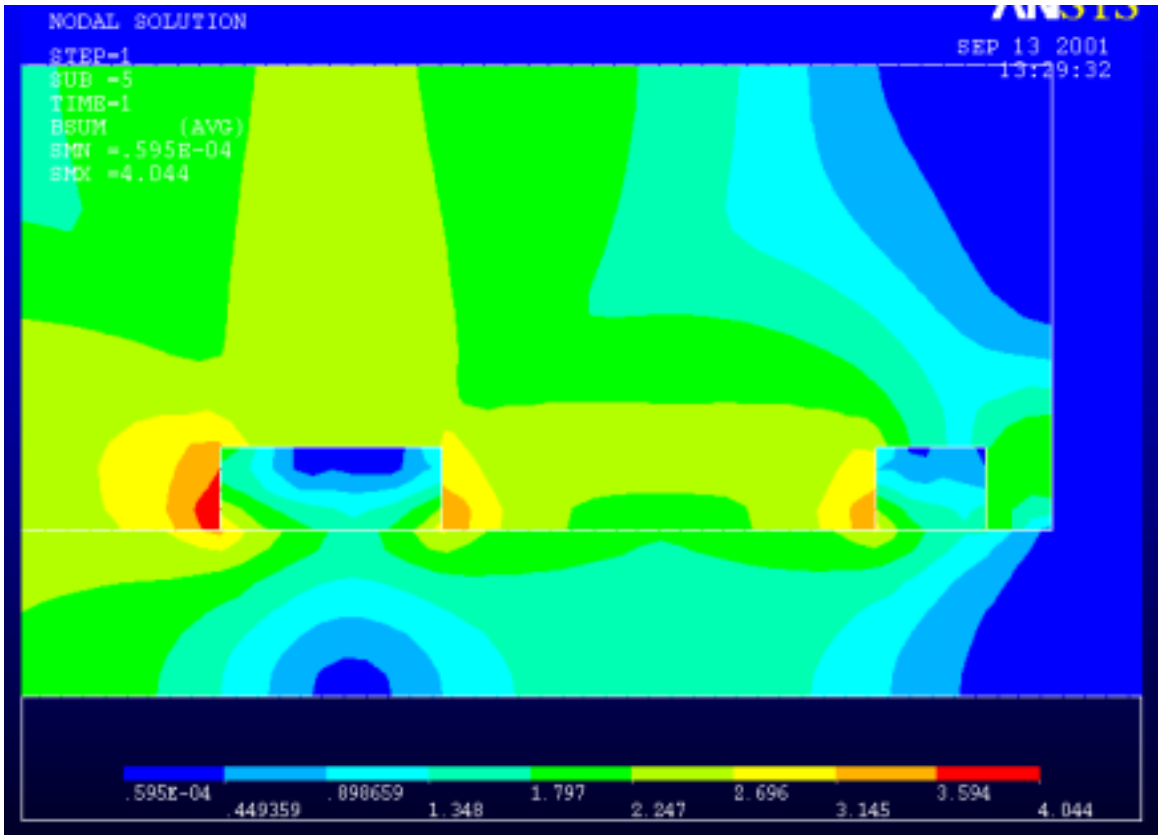

Figure 7: Contour plot of the total magnitude of the magnetic field (in Tesla) for the seven-pole wiggler model. The right most coil groups in Fig. 5 are shown here.

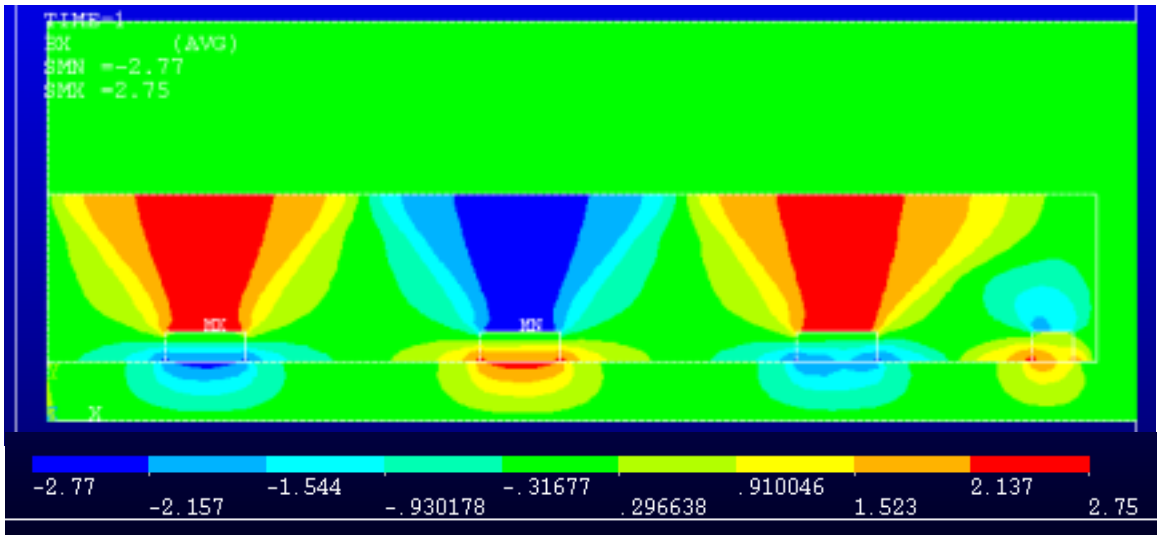

Figure 8: Contour plot of the X-component of the magnetic field (in Tesla) for the seven-pole wiggler model.

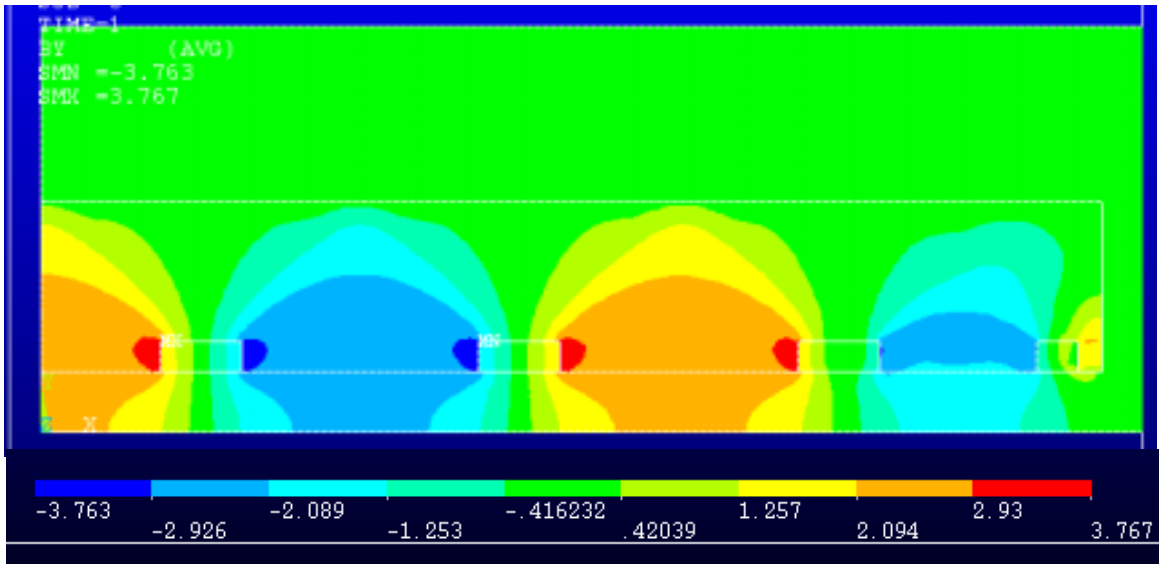

Figure 9: Contour plot of the Y-component of the magnetic field (in Tesla) for the seven-pole wiggler model.

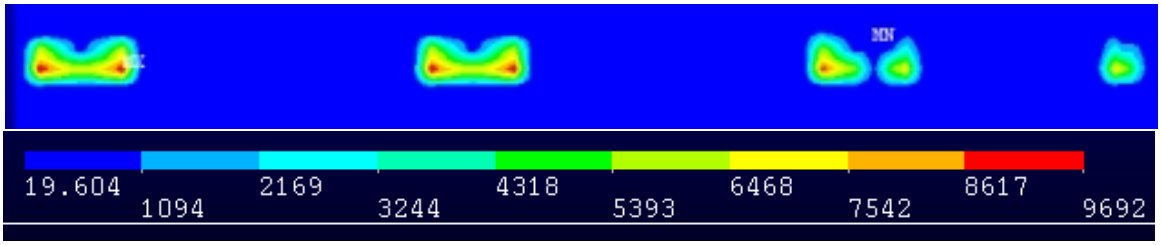

Figure 10: Contour plot of the magnitude of the total Lorentz force (in Newton) for the seven-pole wiggler model.

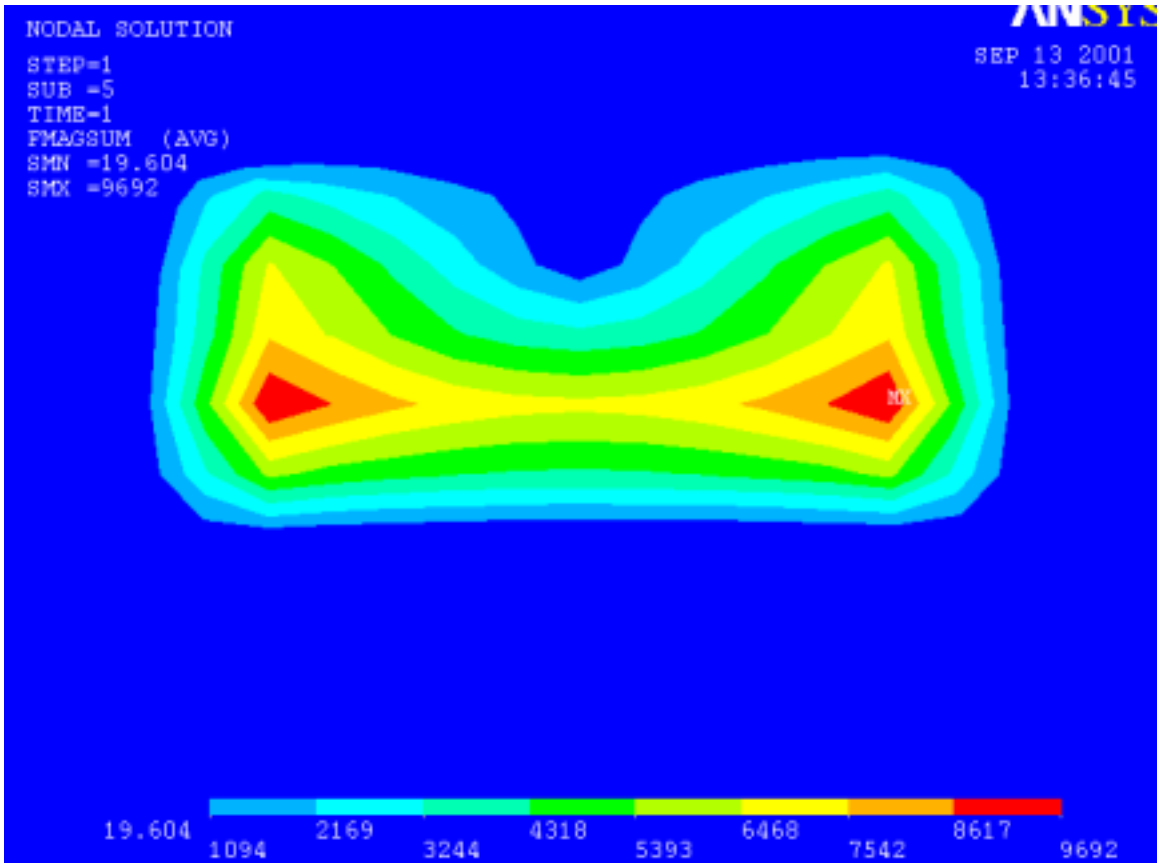

Figure 11: Contour plot of the magnitude of the total Lorentz force (in Newton) for the seven-pole wiggler model. The left most coil group in Fig. 10 is shown here.

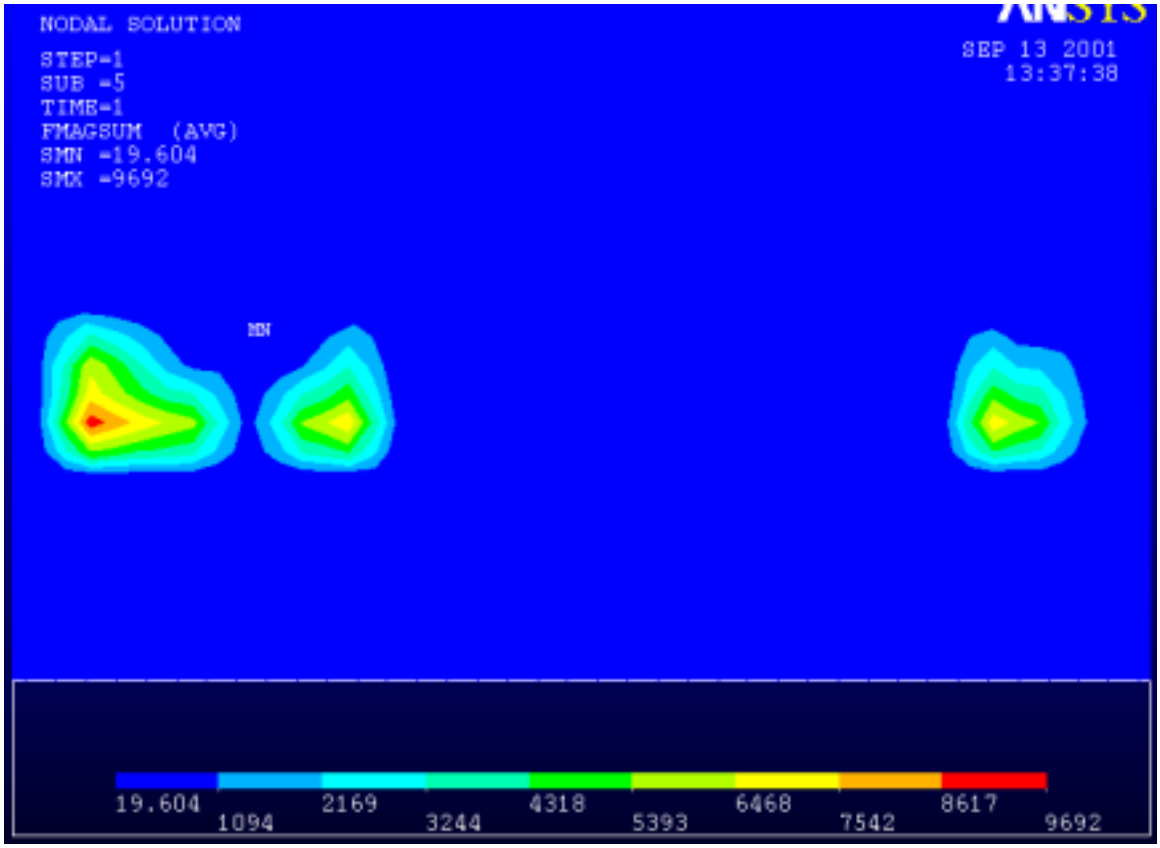

Figure 12: Contour plot of the magnitude of the total Lorentz force (in Newton) for the seven-pole wiggler model. The right most coil groups in Fig. 10 are shown here.

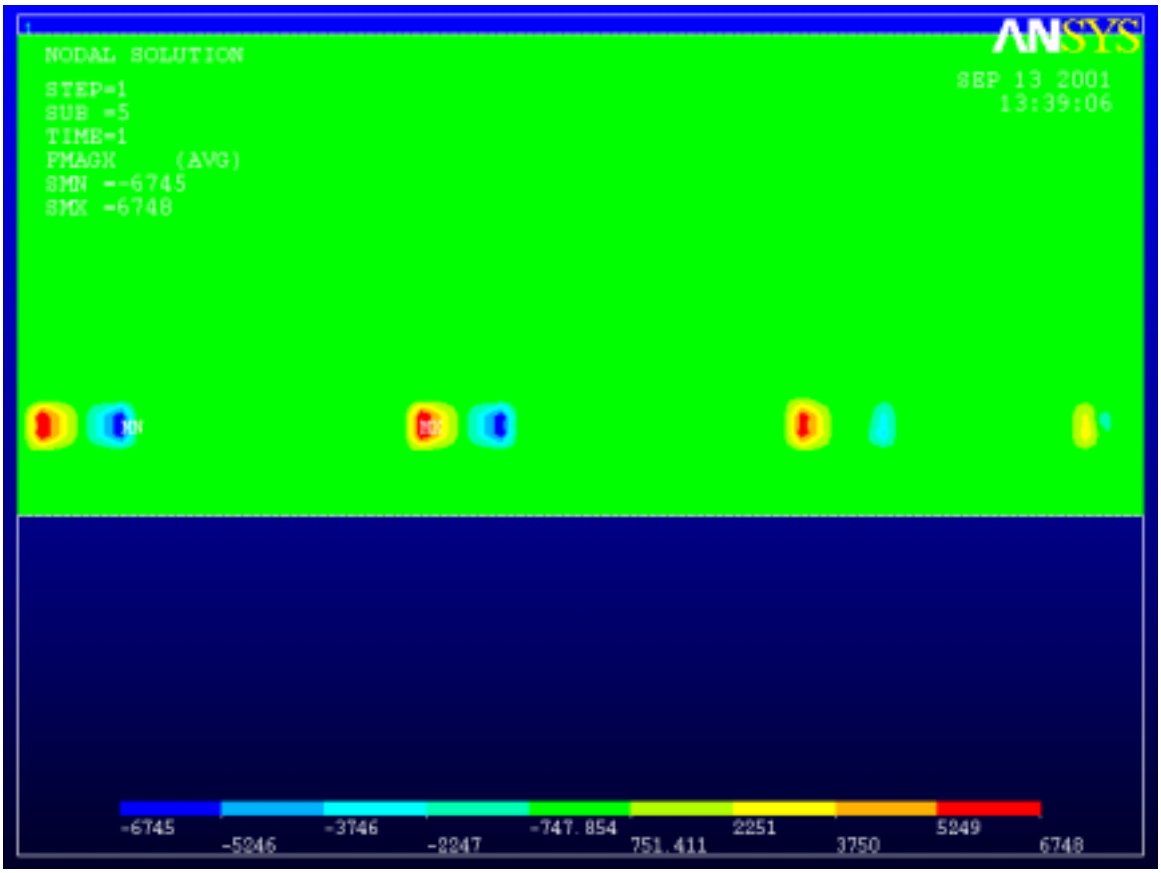

Figure 13: Contour plot of the magnitude of the X-direction Lorentz force (in Newton) for the seven-pole wiggler model.

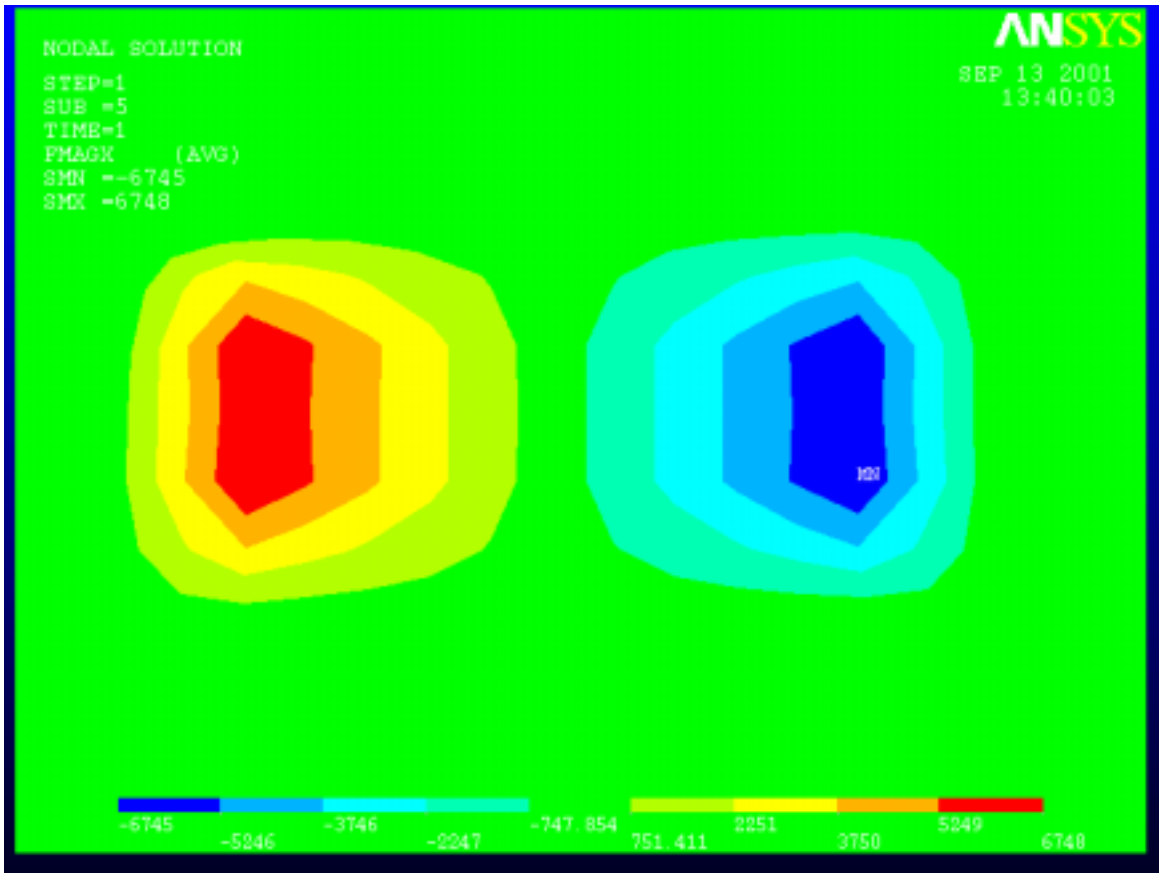

Figure 14: Contour plot of the magnitude of the X-direction Lorentz force (in Newton) for the seven-pole wiggler model. The left most coil group in Fig. 13 is shown here.

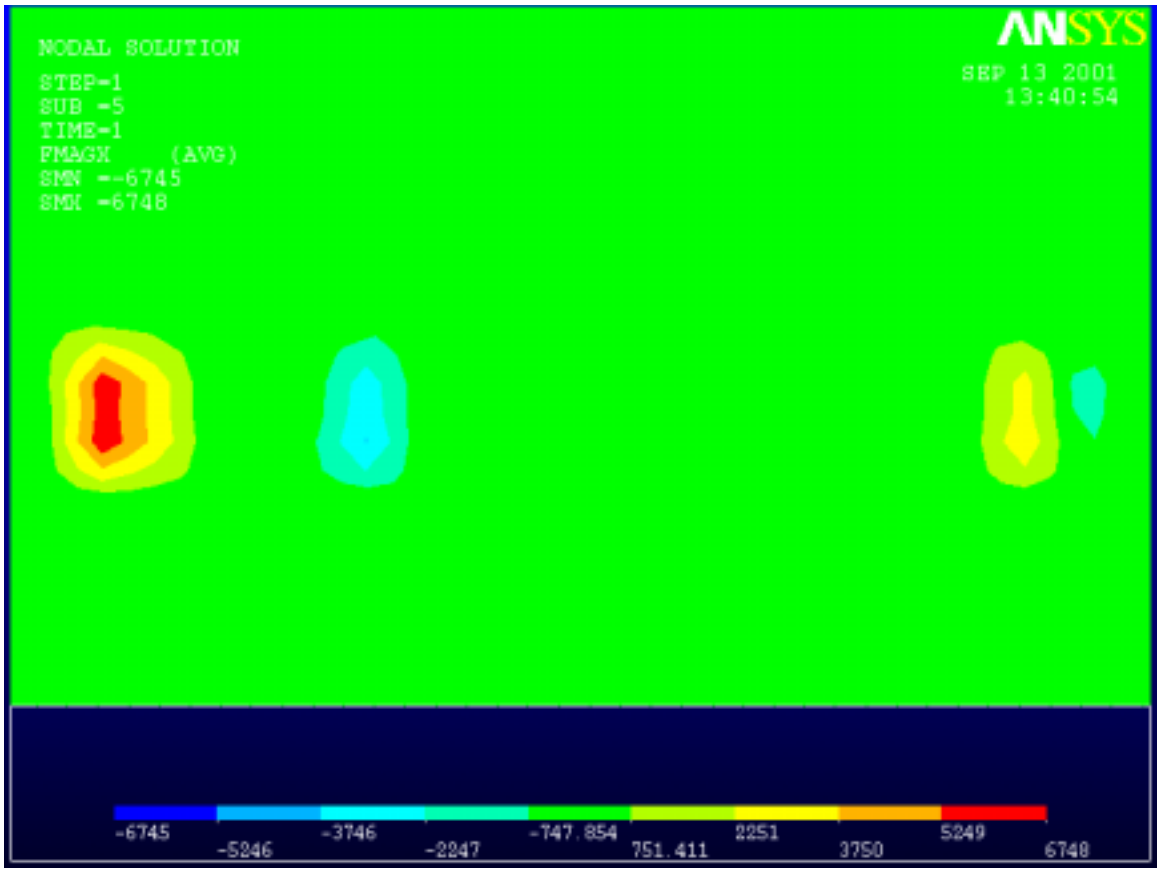

Figure 15: Contour plot of the magnitude of the X-direction Lorentz force (in Newton) for the seven-pole wiggler model. The right most coil groups in Fig. 13 are shown here.

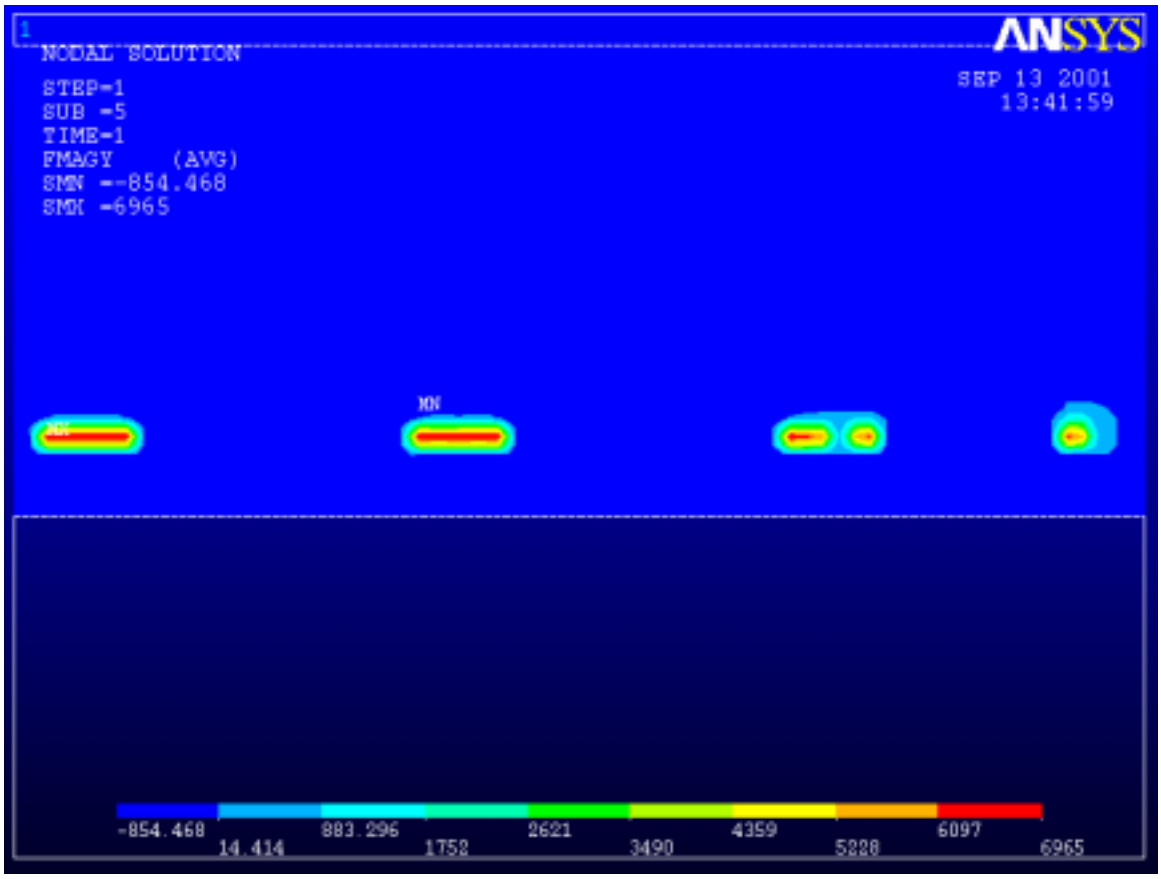

Figure 16: Contour plot of the magnitude of the Y-direction Lorentz force (in Newton) for the seven-pole wiggler model.

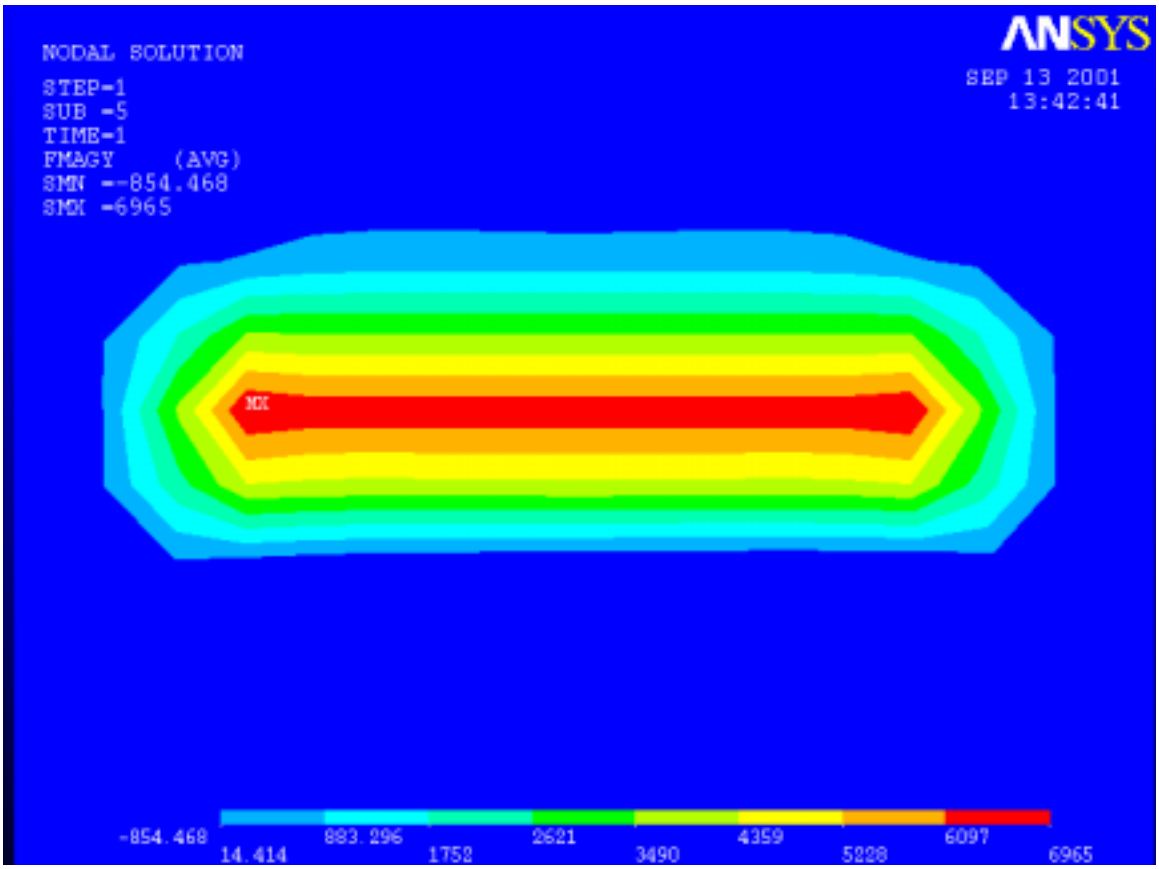

Figure 17: Contour plot of the magnitude of the Y-direction Lorentz force (in Newton) for the seven-pole wiggler model. The left most coil group in Fig. 16 is shown here.

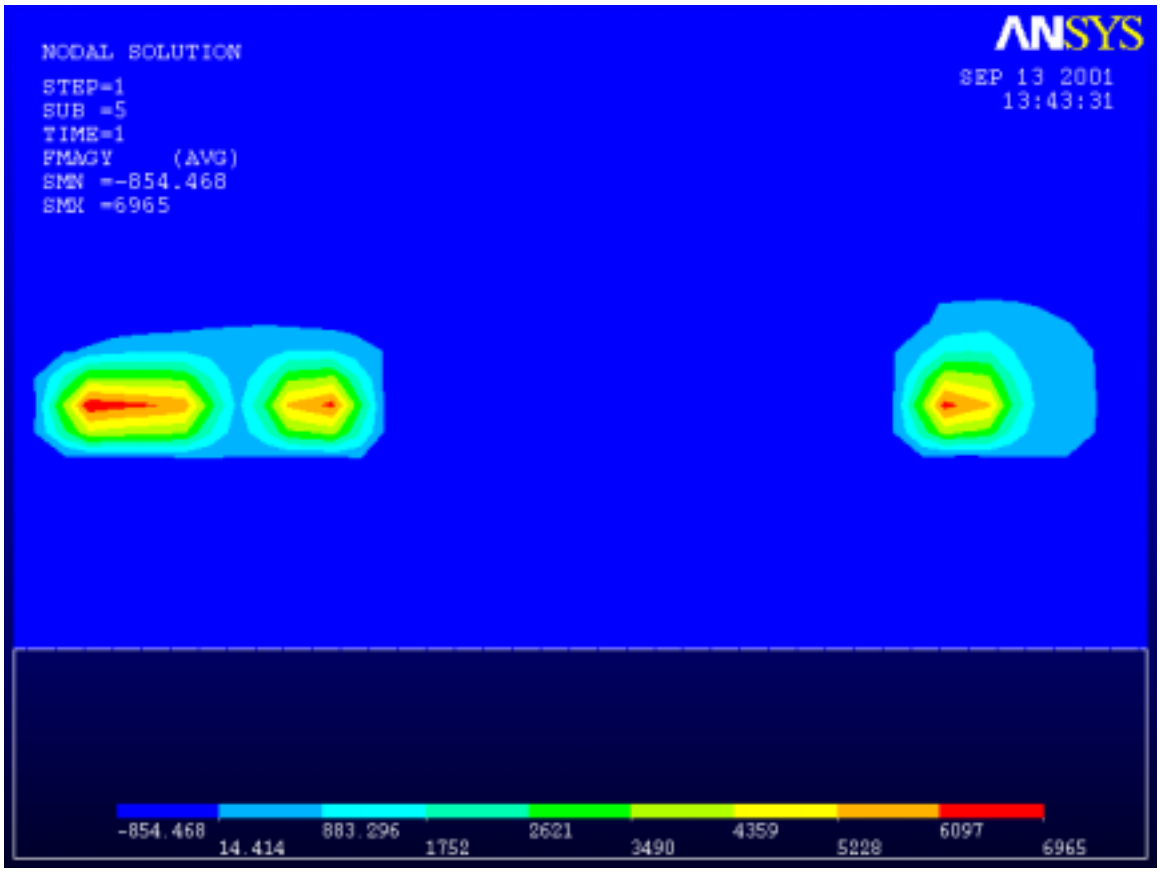

Figure 18: Contour plot of the magnitude of the Y-direction Lorentz force (in Newton) for the seven-pole wiggler model. The right most coil groups in Fig. 16 are shown here.

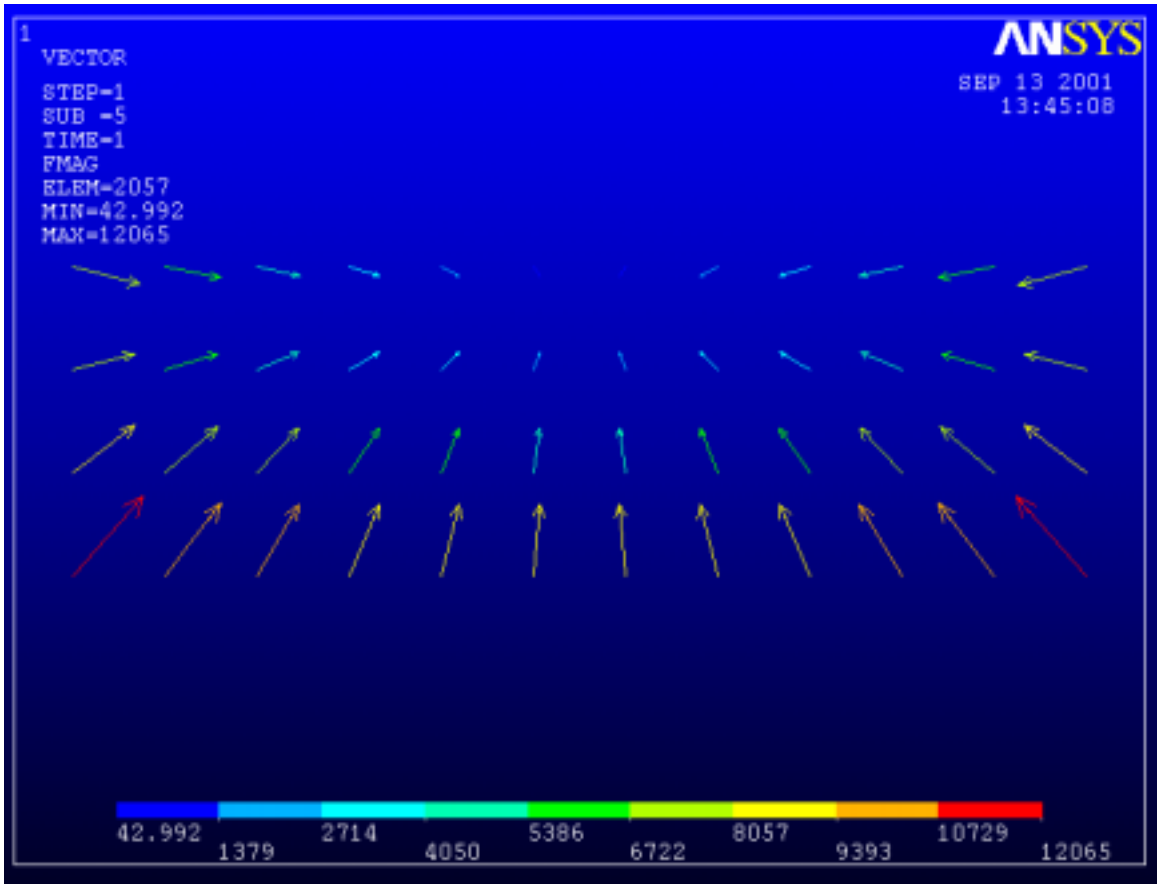

Figure 19: Lorentz force vectors (magnitude in Newton) for the first coil group from the left hand side in Fig. 2.

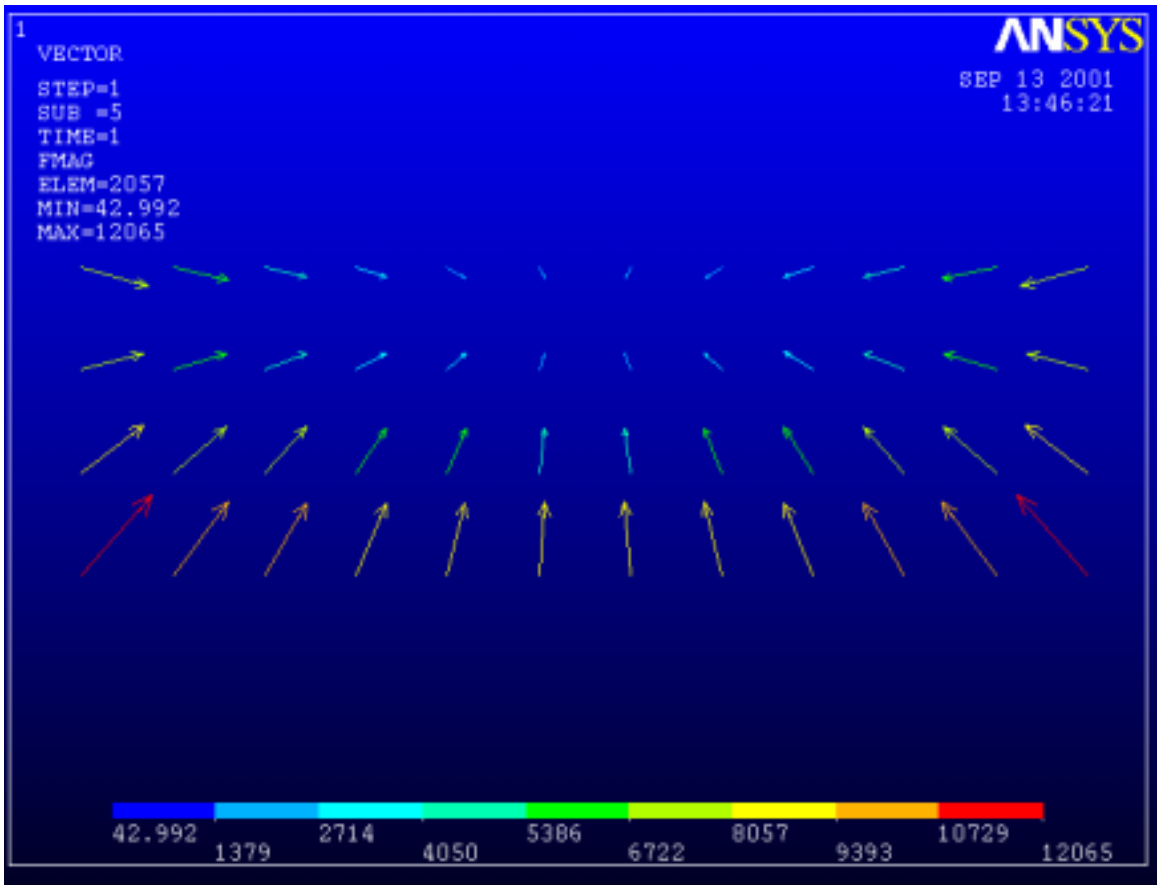

Figure 20: Lorentz force vectors (magnitude in Newton) for the second coil group from the left hand side in Fig. 2.

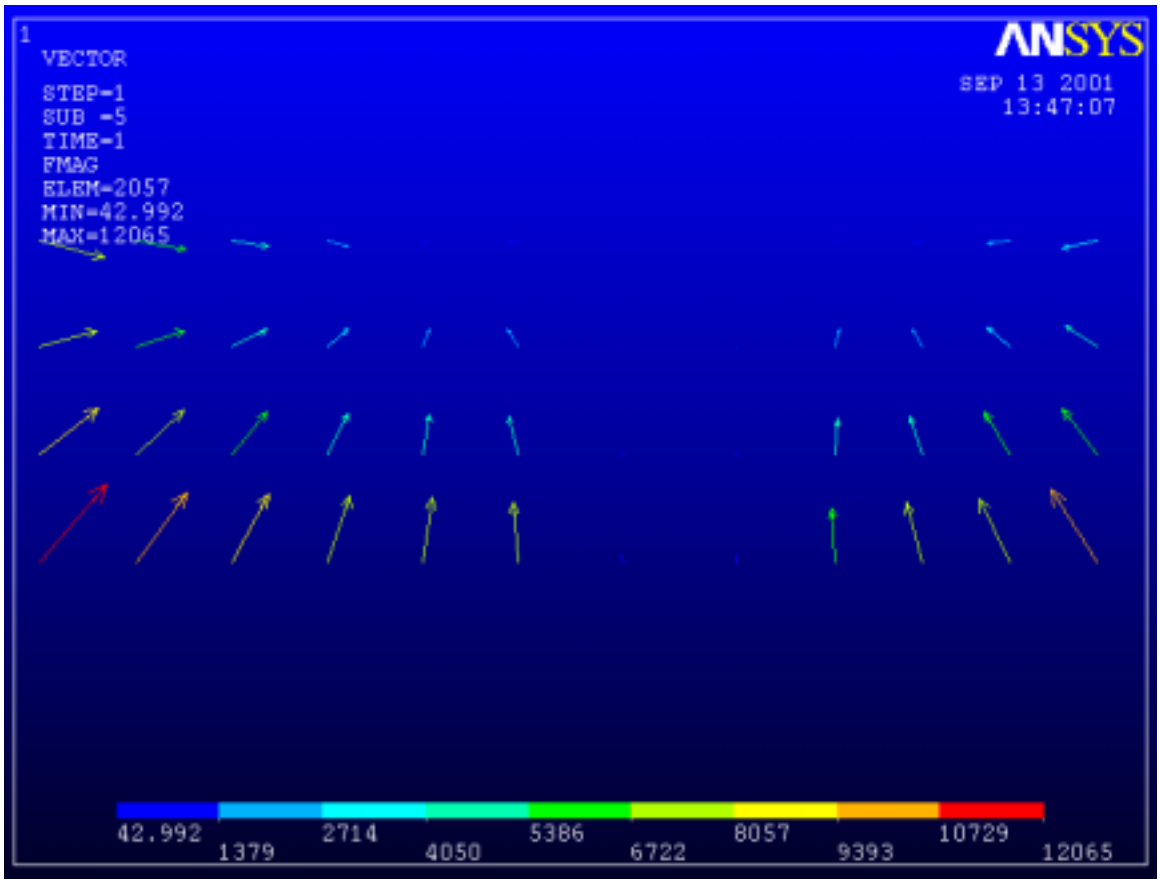

Figure 21: Lorentz force vectors (magnitude in Newton) for the third coil group from the left hand side in Fig. 2.

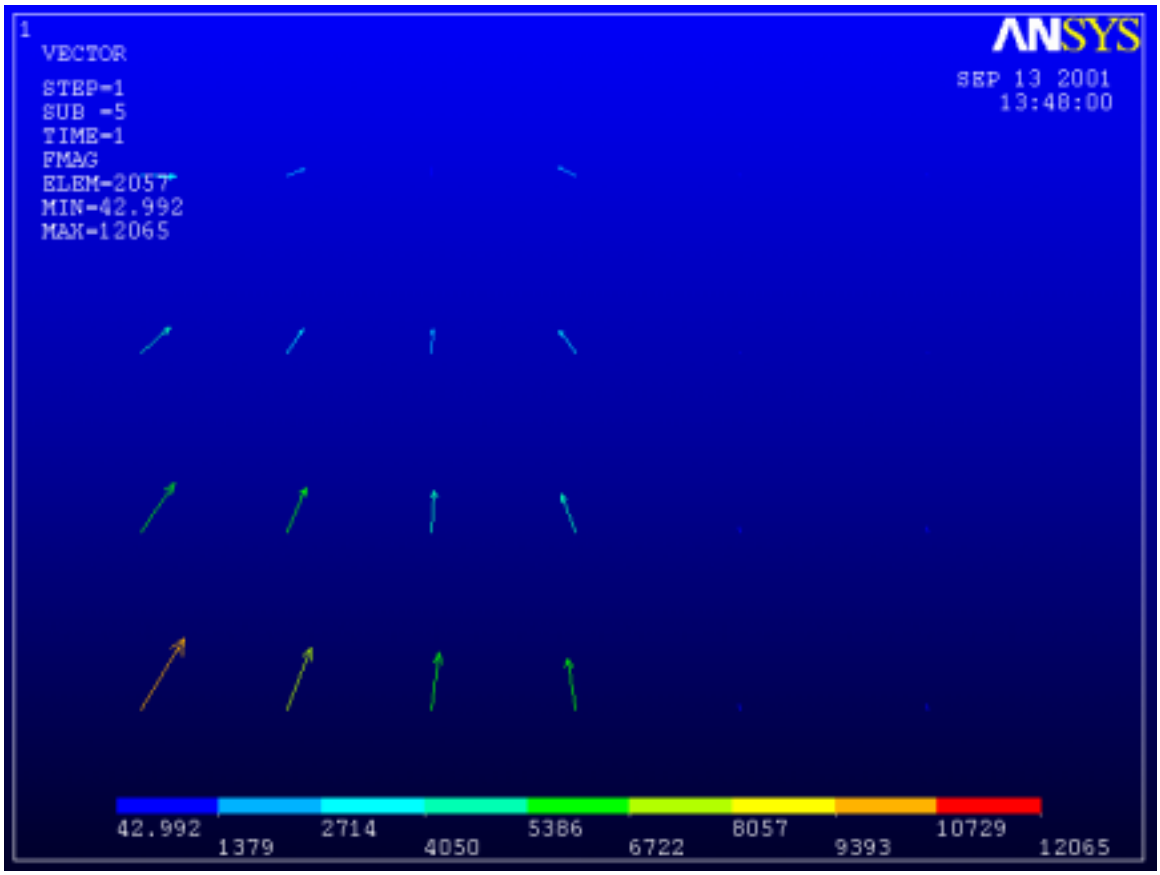

Figure 22: Lorentz force vectors (magnitude in Newton) for the fourth coil group from the left hand side in Fig. 2.

References

[1] G. Dugan,"Two Dimensional ANSYS Models of Seven-Pole Prototype Wiggler," Internal Report, Laboratory of Nuclear Studies, Cornell University, Ithaca, NY, (2001).

[2] S. Yadav, "Finite Element Magnetic Analysis of the Cornell Three-Pole Wiggler Model," Technical Note TD-01-067, Fermi National Accelerator Laboratory, Batavia, IL, (2001).